Wheel Determination of Lego Mindstorms Based on Friction and Wheel Dimensions

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When relying on encoder data for a mobile robot, it is necessary to ensure adequate traction regardless of driving on a slope or flat floor. This paper explores the different options of Lego Mindstorms wheels that are available to measure the best configuration to climb slopes of 20 and 30-degrees using four different types of wheels for the same robot and examines if the different sets of wheels slip. The experiment shows that there is a significant difference in which wheel type is used and which slope the robot is driving up. In other words, the wheel type and the slope have a significant effect on the robot regarding the distance or the time it took to climb.

Keywords* — *Mobile Robot, Hill Ascending, Wheel Optimization, Lego Mindstorm, Traction

1. INTRODUCTION

The use of mobile robots is constantly expanding, and they operate in various environments where the robot needs to know where it is, while it is maneuvering around using sensors and maps to determine its placement. One of the sensors used is an encoder. An encoder tracks the rotational speed of a wheel, and using multiple encoders can be used to calculate the position of the robot based on previous knowledge of the position. Aside from the fact that these sensors have noise, they also rely on the robot's traction to ensure the correct position. If the wheels slide, the position of the robot is offset and without other sensors to keep track of the position, the calculated position and the real-world position are no longer aligned.

There are multiple areas where the traction can cause the robot's wheels to slip, but in this article the area researched is Lego Mindstorm's traction going up on a slope using different wheels. This robot has limited input ports reducing the number of input sensors to four, and if the robot should map its driven route, the encoders need to be trustworthy. If the robot slips, causing the wheels to spin, going up the slope, it would introduce noise to the system and the location would be inaccurate.

A solution to reduce slip from the wheels and increase the liability of the encoders is improving the traction. Multiple wheels and tracks will be evaluated according to traction. The platform to use is a `Lego Mindstorm`. It will drive up a 20° & 30° slope with different wheels, to measure traction. In the test environment, the substrate of the hill is made of paper.

Our problem statement is to find the optimal wheel configuration for the robot to ascend the slope without losing grip, reducing/removing wheel spinning, and prevent the vehicle from completely losing traction and sliding back down. Furthermore, consider the time of ascending the slopes. Thus our hypothesis is that there is a difference in the wheel types for speed integrating our two dependent variables; distance over time.

2. BACKGROUND

The work in this paper targets the issue with mobile robot traction performance when climbing a hill with different wheels. The design of a mobile platform has a big influence on the performance of the platform. The motivation for this project is that different manufacturers of mobile robots primarily use wheels, one of those is Mobile Industrial Robots (MIR) [5], which has one of the state-of-the-art mobile platform systems in climbing slopes. The comparison to the MIR platform is difficult, as the overall system weighs significantly more. According to the specification for a MIR100 platform, the maximum incline is around

5%, which corresponds to around 2.86 degrees. A relevant comparison would be to a robot platform with a smaller form factor eg. a mobile robot platform from Amy Robotics [4], which has a lighter platform that can carry 60 [kg] up a 10-degree slope which is significantly more than MIR. These two systems are built upon fairly old research, and most are looking into other issues than traction on slope comparison. A research article from 2012 [2] is included as it involves comparing different wheel types in an unstructured environment. Under this research, the experiment was carried out on rigid material, and it is therefore comparable with the mentioned article. It is notable that the experiment in the paper concludes the same difference when comparing wheel versus tracked mobile locomotion systems and performance versus speed. Robot track locomotion systems perform better on an unstructured rigid layer, and wheel robot locomotion performs better on a hard structured floor which normally means higher speed.

3. APPROACH

The approach to test the traction is by using a `Lego Mindstorm` that drives on different slopes. To execute the test, the robot needs to know if it is going in a straight line, and when it has reached the top of the hill. This is achieved using two gyroscope sensors to measure the pitch and yaw angle of the robot. The pitch angle tells the system if it has reached the plateau on the top of the slope. The yaw angle is used to ensure the robot drives in a straight line. The robot is seen in figure 1 without wheels attached and the different types of wheels used in the test.

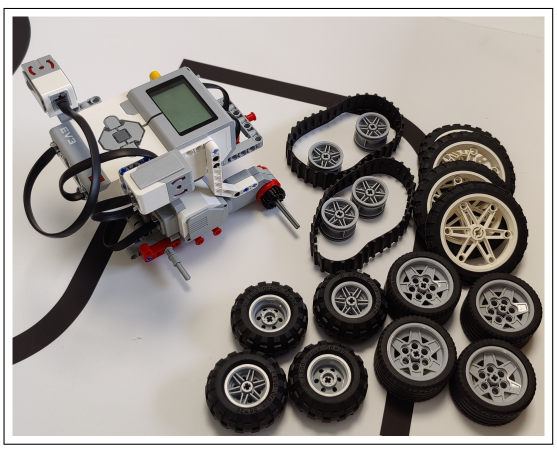


Fig. 1. The built Lego Mindstorm robot platform, with different wheels and tracks.

Figure 1 shows the built robot with three types of wheels and one type of track. The torque is applied to the back axle of the `Lego Mindstorm`. When the wheels are mounted at the same height both in the front and the back to ensure the robot is not angled differently throughout the test.

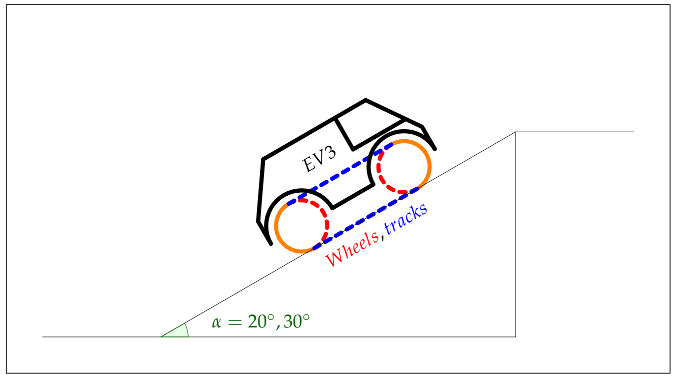


Fig. 2. Illustration of the test system, where the slope of the test track is 20° and 30°. The vehicle shall test different wheels and tracks.

An illustration of the robot driving on the slope can be seen in figure 2. The starting point is at the bottom of the slopes, and the end position is when the robot reaches the top of the slopes.

Fig. 3. Lego Mindstorm ascending 30° slope with tracks.

Figure 3 shows the mobile robot driving up the 30-degree slope in our testing environment using tracks.

4. THE EXPERIMENT

The data for the robot required consistency in order to be valid. Relying on a fixed motor speed for two wheels resulted in lots of failures, where the robot turned into the wall. Therefore, a controller was implemented. The controller used a gyroscope to measure the yaw angle of the robot. A P-controller used this data to regulate the motors, which delivered consistent ascends with the same duty cycle output for all the wheels.

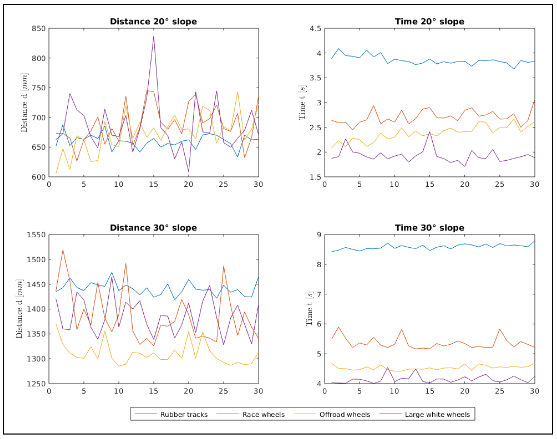
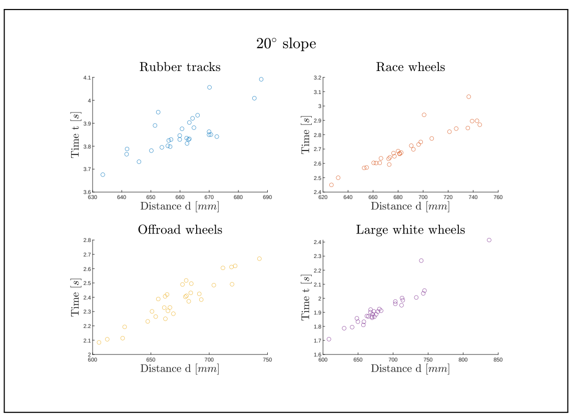
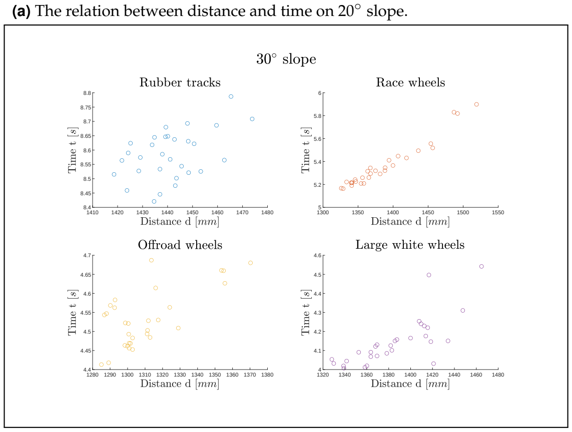


Fig. 4. The raw data from 20° & 30° slope. It displays the 20° slopes at the top, and 30° in the bottom. The left side is for distance, and the right is for time.

Another gyroscope was used to measure the pitch. The pitch on the bottom floor is the same as on the top floor. This is because the floors are parallel. With this information, the robot was able to detect when it had ascended the hill, so it automatically stopped the timer and calculated the total driven distance. From the experiments, the following data gathered through the experiment, see figure 4.



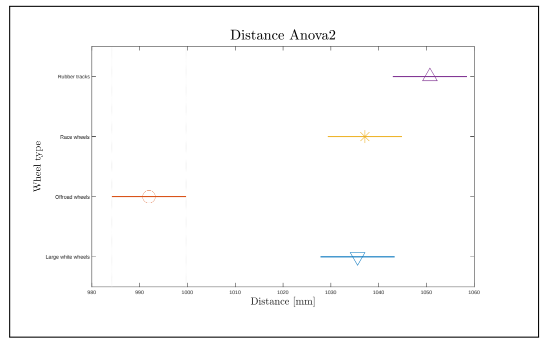
(a) The relation between distance and time on 20° slope.



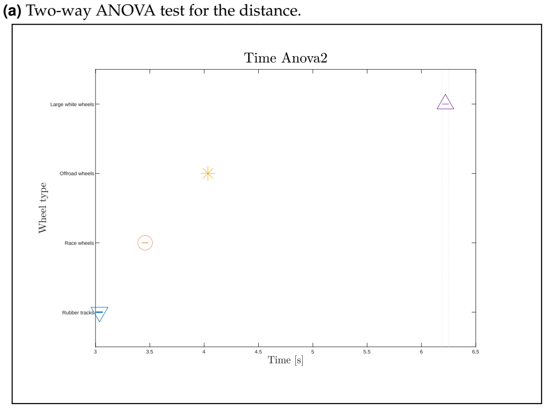
(b) The relation between distance and time on 30° slope.

Fig. 5. The relation between distance travelled along the slope and the corresponding time.

Figure 5 shows the data for this experiment and the relation between distance and time for each experiment. In this project, there are two dependent variables, time and distance, and two independent variables. The wheel type has four levels, which are the Rubber Wheel, Off-road wheels, Race wheel, and Large white wheel. The second independent variable is the slope, which has two levels, a 20-degree slope, and a 30-degree slope. For this project, two separate statistical studies are performed. One for each dependent variable, cause there is no linear relation between the two dependent variables as seen in figure 5. The data presented in this experiment are assumed to be normally distrusted. However, since there are two independent variables and the data is normally distributed, the two-way ANOVA test is applied.



(a) Two-way ANOVA test for the distance.



(b) Two-way ANOVA test for the time.

Fig. 6. Two-way ANOVA test

Figure 6 shows the multiple comparisons of the means for the distance. Looking at figure 6a, it shows that the mean of the Offroad wheels differ from the three others, and as the other three comparison intervals intersect, they are not significant different. For the time, shown in figure 6b, the comparison intervals of the four wheel types are completely separated, therefore all groups are significantly different from each other.

The results for the two-way ANOVA for the distance the p-values are $p = 5.17349e\text{-}19$ for the wheel types and $p = 2.30338e\text{-}242$ for the slopes, and $p = 5.11395e\text{-}24$ for the interaction between the slope and wheel type. These indicate that the slope and wheel type affect the robot as well as the interaction between the two.

As for the two-way ANOVA for the time the p-values are $p = 19.111e\text{-}227$ for the wheel types and $p = 8.58678e\text{-}248$ for the slopes, and *p = 1.53339e-144* for the interaction between the slope and wheel type. As in the distance, the p-value shows that time is affected by both wheel type and slope inclination. Therefore the null hypnosis is rejected.

5. DISCUSSION

The gyro sensor tells the robot to stop when it reaches the end of the slope where the measurement is notated, this could variate depending on the different wheel and result in adding a delay to the gyro sensor. Besides that, the gyro sensor of the robot is not one hundred percent accurate, so the consumption is that some noise is added to the dependent variables for both distance and time.

The experiment was repeated 30 times for each independent variable. The data presented in this experiment ends up not being normally distributed, even though we assume normality. The abnormal distribution data is more obvious in the 30-degree slope. The noise is difficult to measure, but some research has been done to test gyro accuracy on the Lego Mindstorms sensors. According to EV3 Basic, [1] a fairly short but useful experiment has been made to discuss the uncertainty of the gyro sensor, the results are hard to compare to our system, but overall the faster a decent and change in rotation the smaller is the issue with accuracy. The difference in clockwise and counterclockwise also have an impact on precision, as well as speed. Intuitively one would assume that the slower the gyro moves the more time it has it refine the resulting value, but according to the research [1], the experience is the opposite.

6. FUTURE WORK

The conducted experiments were measurements of a robot ascending a slope. It would be interesting to see how the robot would behave on descending the slopes.

Also changing the substrate of the slope would be interesting to see how much it affects the robots ability to ascend a slope.

Another used mobile robot is the turtlebot. Using two wheels and an omni-directional wheel either in front or in the back, enabling the `Lego Mindstorm` to turn in place and increase maneuverability. The omni-directional wheel is made of metal and if the center of mass is above this wheel during ascend and decent, the robot slides down. Changing the build of the robot and ensuring the center of mass is located the correct place, it would be interesting to see if a robot could both drive up and down without slipping.

To extend the statistical analysis, more test could been completed. If the experiment was increased in number of tests, inserting 5-degree incremented inclinations starting from 5 to 20-degree and excluding the uncertainty of the 30-degree slope, the extended statistical analysis could have been further exploited.

As previously it have been shown that the sensors used in this system comes from the `EV3 Lego Mindstorms`, and shows poor performance on the gyro sensor. Additionally a sensor calibration could have been made prior to the data collection, to ensure correct readings. A guide [3] could have been used to create a software oriented calibration on the gyro sensor, if the difference in readings had been a significant change is hard to know, as Lego does not provide a solution for calibration itself.

7. CONCLUSION

The experiment concludes the rejectence of the null hypnosis and states that there are significantly different in the mean in both independent variables, therefore the wheel type and the slope have an effect on the robot regarding the distance travelled or the time it took to climb. To achieve the fastest slope climb, the large wheel is the optimal solution as it reaches the top in the fastest time. The reason for this is that there isn't a big issue with traction for the different wheel types, and the torque applied from the motors are strong enough to accelerate the wheels to the maximum speed in small difference between the wheels, the only factor for reaching the top, is the radius of the wheel since the rpm is the same.

8. BACKMATTER

Disclosures. The authors declare no conflicts of interest.

Data availability. Data underlying the results presented in this paper are available in [6], under the assumption that a invitation has been sent. The GitHub repository is naturally not public available, but the data is freely distributed upon request.

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